

Status of Dynamical Coupled-Channel analysis by Collaboration@EBAC

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Abstract. The development and results of the Dynamical Coupled-Channels analysis by a collaboration at the Excited Baryon Analysis Center (EBAC) are reported.

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INTRODUCTION

In this contribution, we report on the development and results from a dynamical coupled-channel (DCC) analysis by a collaboration associated with the Excited Baryon Analysis Center (EBAC) at Jefferson Lab during the period January, 2006 - March, 2012. This project has three components : (1) perform a dynamical coupled-channels analysis on the *world* data on meson production reactions from the nucleon to determine the meson-baryon partial-wave amplitudes, (2) extract the N^* parameters from the determined partial-wave amplitudes, and (3) investigate the interpretations of the extracted N^* properties in terms of the available hadron models and Lattice QCD.

DCC MODEL

The DCC analysis by the collaboration@EBAC is based on an extension [1] of the dynamical model for the $\Delta(1232)$ resonance developed [2] by an Argonne National Laboratory-Osaka University (ANL-Osaka) collaboration. Within the extended ANL-Osaka formulation [1], the reaction amplitudes $T_{\alpha,\beta}(p, p'; E)$ in each partial-wave are calculated from the following coupled-channels integral equations,

$$T_{\alpha,\beta}(p, p'; E) = V_{\alpha,\beta}(p, p') + \sum_{\gamma} \int_0^{\infty} q^2 dq V_{\alpha,\gamma}(p, q) G_{\gamma}(q, E) T_{\gamma,\beta}(q, p', E), \quad (1)$$

$$V_{\alpha,\beta} = v_{\alpha,\beta} + \sum_{N^*} \frac{\Gamma_{N^*,\alpha}^{\dagger} \Gamma_{N^*,\beta}}{E - M^*}, \quad (2)$$

where $\alpha, \beta, \gamma = \gamma N, \pi N, \eta N, KY, \omega N$, and $\pi\pi N$ which has $\pi\Delta, \rho N, \sigma N$ resonant components, $v_{\alpha,\beta}$ are meson-exchange interactions deduced from phenomenological Lagrangian, $\Gamma_{N^*,\beta}$ describes the excitation of the nucleon to a bare N^* state with a mass M^* , and $G_{\gamma}(q, E)$ is a meson-baryon propagator. The DCC model, defined by Eqs. (1) and (2), satisfies two- and three-body unitarity conditions.

In order to determine the parameters associated with the strong-interaction parts of $V_{\alpha,\beta}$ in Eq. (2), the considered DCC model was first applied to fit the πN elastic scattering up to invariant mass $W = 2$ GeV. For simplicity, KY and ωN channels were not included during the development stage in 2006-2010. The electromagnetic parts of $V_{\alpha,\beta}$ were then determined by fitting the data of $\gamma p \rightarrow \pi^0 p, \pi^+ n$ and $p(e, e' \pi^{0,+})N$.

The resulting 6-channel model was then tested by comparing the predicted $\pi N, \gamma N \rightarrow \pi\pi N$ production cross sections with the data. In parallel to analyzing the data, a procedure to analytically continue Eqs. (1) and (2) to the complex energy plane was developed to extract the positions and residues of nucleon resonances.

In the following, we present a sample of results from these efforts.

Results for single pion production reactions

In fitting the πN elastic scattering, we found that one or two bare N^* states were needed in each partial wave. The coupling strengths of the $N^* \rightarrow MB$ vertex interactions $\Gamma_{N^*,MB}$ with $MB = \pi N, \eta N, \pi\Delta, \rho N, \sigma N$ were then determined in the χ^2 -fits to the data. Our results were given in Ref. [3].

Our next step was to determine the bare $\gamma N \rightarrow N^*$ interaction $\Gamma_{N^*,\gamma N}$ by fitting the $\gamma p \rightarrow \pi^0 p$ and $\gamma p \rightarrow \pi^+ n$ data. We found [4] that we were able to fit the data only up to invariant mass $W = 1.6$ GeV, mainly because we did not adjust any parameter which was already fixed in the fits to πN elastic scattering. Some of our results for total cross sections (σ), differential cross sections ($d\sigma/d\Omega$), and photon asymmetry (Σ) are shown in Fig. 1.

The Q^2 -dependence of the $\Gamma_{N^*,\gamma N}$ vertex functions were then determined [5] by fitting the $p(e, e' \pi^0)p$ and $p(e, e' \pi^+)n$ data up to $W = 1.6$ GeV and $Q^2 = 1.5$ (GeV/c)².

Results for two-pions production reactions

The model constructed from fitting the data on single pion production reactions was then tested by examining the extent to which the $\pi N \rightarrow \pi\pi N$ and $\gamma N \rightarrow \pi\pi N$ data can be described. It was found [6, 7] that the predicted total cross sections are in excellent agreement with the data in the near threshold region $W \leq 1.4$ GeV. In the higher W region, the predicted $\pi N \rightarrow \pi\pi N$ cross sections can describe to a very large extent the available data, as shown in Fig. 2. Here the important role of the coupled-channel effects were also demonstrated. However, the predicted $\gamma p \rightarrow \pi^+ \pi^- p, \pi^0 \pi^0 p$ cross sections were a factor of about 2 larger than the data while the shapes of two-particles invariant mass distributions could be described very well.

Resonance Extractions

We follow earlier work, as reviewed and explained in Refs. [8, 9], to define that the resonances are the eigenstates of the Hamiltonian with only outgoing waves of their

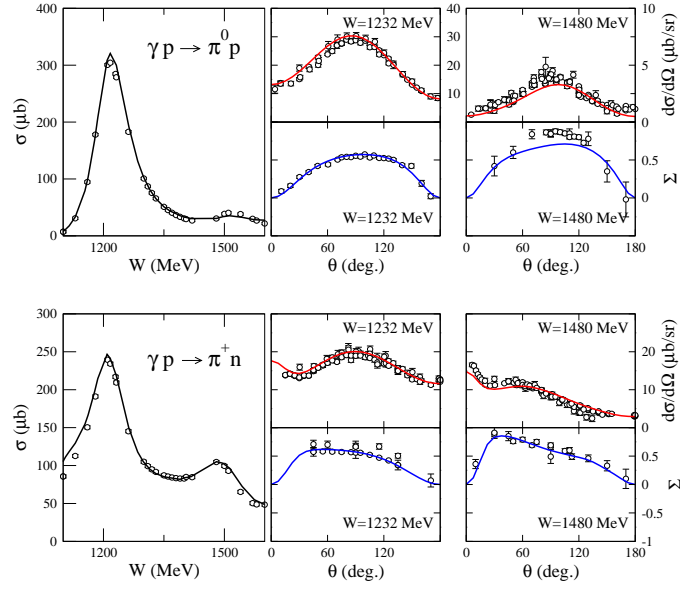


FIGURE 1. The DCC results [4] of total cross sections (σ), differential cross sections ($d\sigma/d\Omega$), and photon asymmetry (Σ) of $\gamma p \rightarrow \pi^0 p$ (upper parts), $\gamma p \rightarrow \pi^+ n$ (lower parts).

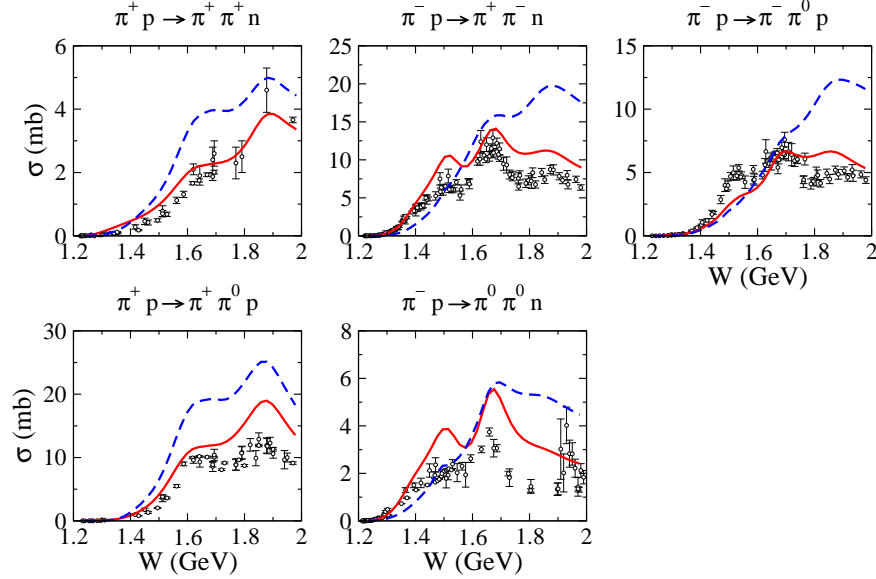


FIGURE 2. The predicted [6] total cross sections of the $\pi N \rightarrow \pi\pi N$ are compared with the data. The dashed-curves are obtained when the coupled-channel effects are turned off within the DCC model of Ref.[1].

decay channels. One can then show that the nucleon resonance positions are the poles M_R of meson-baryon scattering amplitudes calculated from Eqs. (1) and (2) on the unphysical sheets of complex- E Riemann surface. The coupling of meson-baryon states with the resonances can be determined by the residues $R_{N^*,MB}$ at the pole positions. Our

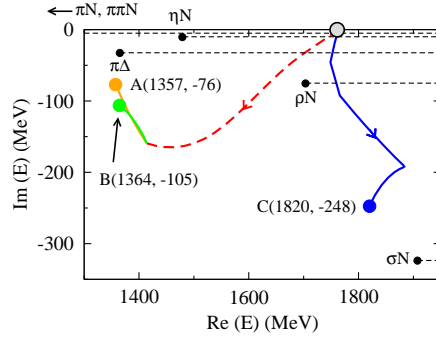


FIGURE 3. The trajectories of the evolution of three nucleon resonances in P_{11} from the same bare N^* state. The results are from Ref. [10].

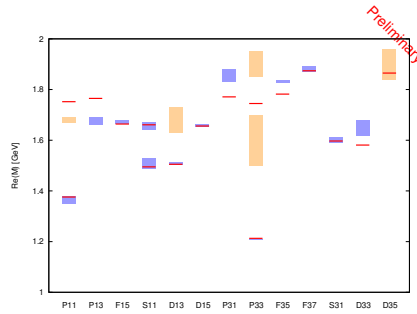


FIGURE 4. Preliminary results (red bars) of the determined N^* spectrum are compared with 4-star (blue bands) and 3-star (brown bands) states listed by the Particle Data Group.

procedures for determining M_R and $R_{N^*,MB}$ and the results were presented in Refs. [8, 9, 10, 11].

With our analytic continuation method [8, 9], we were able to analyze the dynamical origins of the nucleon resonances extracted from the considered DCC model of Ref.[1]. This was done by examining how the resonance positions move as the coupled-channels effects are gradually turned off. As illustrated in Fig. 3 for the P_{11} states, this exercise revealed that the two poles in the Roper region and the next higher pole are associated with the same bare state.

PROSPECT

During the developing stage of DCC analysis by Collaboration@EBAC in 2006-2010, the DCC model parameters were determined by analyzing separately the following data: $\pi N \rightarrow \pi N$ [3], $\gamma N \rightarrow \pi N$ [4], $N(e, e' \pi) N$ [5], $\pi N \rightarrow \pi \pi N$ [6], and $\gamma N \rightarrow \pi \pi N$ [7]. The very extensive data on $K\Lambda$ and $K\Sigma$ production were not included in the analysis. To have a high precision extraction of nucleon resonances, it is necessary to perform a *combined* simultaneous coupled-channels analysis of all meson production reactions.

We started an 8-channels combined analysis of *world* data of $\pi N, \gamma N \rightarrow$

$\pi N, \eta N, K\Lambda, K\Sigma$ since the summer of 2010. Only the preliminary results had been obtained by March 31, 2012 when the Collaboration@EBAC was dissolved. In Fig.4, we show the determined excited nucleon spectrum from this combined analysis. An ANL-Osaka collaboration has since taken over this task and we expect to complete the analysis by the end of 2012. The ANL-Osaka analysis will then proceed to extracting $\gamma N \rightarrow N^*$ form factors up to sufficiently high Q^2 from the *new* JLab data on meson electroproduction data. In addition, we will explore the interpretations of the extracted resonance parameters in terms of available hadron models, such as the Dyson-Schwinger-Equation model and constituent quark model, and Lattice QCD. This last step is needed to complete the DCC project with conclusive results, as discussed in Refs.[1, 2, 10, 12].

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